

# **DISTRIBUTED AIR/GROUND TRAFFIC MANAGEMENT: RESULTS OF PRELIMINARY HUMAN-IN-THE-LOOP SIMULATION**

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## **Introduction**

In September 2002, NASA's Advanced Air Transportation Technologies project office sponsored a human-in-the-loop simulation of Distributed Air/Ground Traffic Management (DAG-TM) concepts. The simulation examined three DAG-TM Concept Elements (CEs) which included:

- CE 5:** En Route Free Maneuvering for (a) User-Preferred Separation Assurance, and (b) User-Preferred Local Traffic Flow Management (TFM) Conformance
- CE 6:** Trajectory Negotiation for (a) User-Preferred Separation Assurance, and (b) User-Preferred Local TFM Conformance
- CE 11:** Terminal Area Self-Spacing for Merging and In-Trail Separation

The test airspace for the simulation encompassed four en route sectors and one Terminal Radar Approach Control (TRACON) sector. The participating controllers used Center TRACON Automation System (CTAS) tools, and the participant pilots used Cockpit Situation Displays (CSDs). The CSD had a conflict detection and manual resolution capability.

There were twelve runs, each approximately seventy-five minutes in duration. Roughly half of the aircraft were arrivals, which flew through two or more en route sectors, before entering the TRACON via a meter fix at a scheduled time. The study involved three experimental conditions: a baseline that approximated current operations, CE

6: Trajectory Negotiation operations, and CE 5: Free Maneuvering mode of operation. In CE 6, the equipped aircraft were allowed to request trajectory changes. In CE 5, the equipped aircraft were allowed to change trajectories without clearance from a controller. Both CE 5 and CE 6 operations facilitated CE 11 operation in the TRACON airspace. The results indicated that in CE 5 and CE 6 conditions, the controllers appeared better able to meet the meter fix arrival schedule and appeared to provide a more consistent feed to the TRACON controller. The arrival spacing variance appeared smaller in CE 5 and CE 6 conditions as compared to the baseline condition. The preliminary analysis and participant pilot and controller feedback indicated that the examined CEs, as simulated, may be potentially feasible. Both controllers and pilots provided useful suggestions regarding tool usability, procedures, and concept elements. These are preliminary studies related to DAG-TM, therefore results must be treated with caution. The DAG-TM research will continue in upcoming years.

## **Background**

The DAG-TM study is a continuation of a number of ongoing research activities at NASA Ames, Langley, and Glenn Research Centers. Until recently, the research and development on air- and ground-side tools relevant to the DAG-TM environment has been focused on the technical and information requirements for individual user groups. Tools for controllers and pilots were developed independently of each other, or in part-task simulations involving limited interaction among different user groups [1,2,3,4]. For example,

the Airborne User of Traffic Intent Information (AUTRII) study investigated two forms of traffic intent information on pilot performance and acceptance [5]. This study provided pilots with real-time display information and feedback on a Cockpit Display of Traffic Information (CDTI). On the ground side, Kerns studied the usefulness of the User Request Evaluation Tool (URET) on controller performance in an unstructured environment [6].

The incremental research approach that has been applied to this point is consistent with the FAA's "build a little, test a little, demonstrate a little" principle. This approach is necessary and appropriate in the early stages of research in a complex environment such as DAG-TM, as it allowed researchers to focus on specific issues related to the individual user groups under bounded conditions.

Recently, however, researchers conducted an integrated air-ground study to investigate the impact of shared separation on user tasks, performance, and workload. The Air-Ground Integration Experiment (AGIE) was the first real-time human-in-the-loop simulation to investigate the effect of different levels of shared-separation authority, including current day operations, on air and ground operations [7]. The shared-separation concepts were based on RTCA definitions of free flight [8]. Participants were provided with tools to aid them in completing the task required to enable shared separation. In this study, pilot participants interfaced with a CDTI that provided conflict alerts, traffic aircraft flight path predictors, and conflict location predictors. In addition to the current-day display system replacement (DSR), controller participants had URET available to aid them in predicting and evaluating potential conflicts between aircraft. To emulate future technologies, the study included support tools to facilitate communication in the distributed environment. A researcher served as an automatic datalink operator to simulate the transfer of Automatic Dependent Surveillance-Broadcast (ADS-B) data (such as unscheduled altitude or course changes) to participants, and members of the research team staffed additional aircraft and sector controller positions to increase the realism of the simulation.

Results of the AGIE indicated that controller participants rated safety under the shared-separation conditions as compromised as compared to current day operations. Controllers were concerned about the length of time pilots required to respond to conflict alerts, and they felt that the pilots tended to fly closer to traffic aircraft than controllers would usually allow [7]. These factors contributed to an increase in controller stress and workload. Conversely, controller participants rated the information to resolve conflicts and the URET look-ahead time as adequate in all test conditions. Pilot participants reported higher workload in the shared-separation conditions, but the workload measures were never above the moderate level [7]. The AGIE pilot participants did not report the concerns about compromised safety that the controllers reported. Pilot participants had favorable comments in general about the decision support tools (DSTs) and procedures implemented in the AGIE. Feedback from the AGIE controller participants provided researchers with valuable information to understand the issues that needed to be addressed with regard to implementing shared-separation concepts in the future. Since the number of pilot participants in the study was low, and because of limitations in the operational context of the simulation (i.e., there were no weather or abnormal events), results from the pilots' data could not be generalized. Researchers noted that differences in the controllers' and pilots' conflict resolution strategies and the time required for the two groups to respond to a conflict situation may have resulted in the discrepancies in safety ratings. One of the reasons for this study is to examine CE 5, 6, and 11 concepts in an air-ground integration environment.

## **Method**

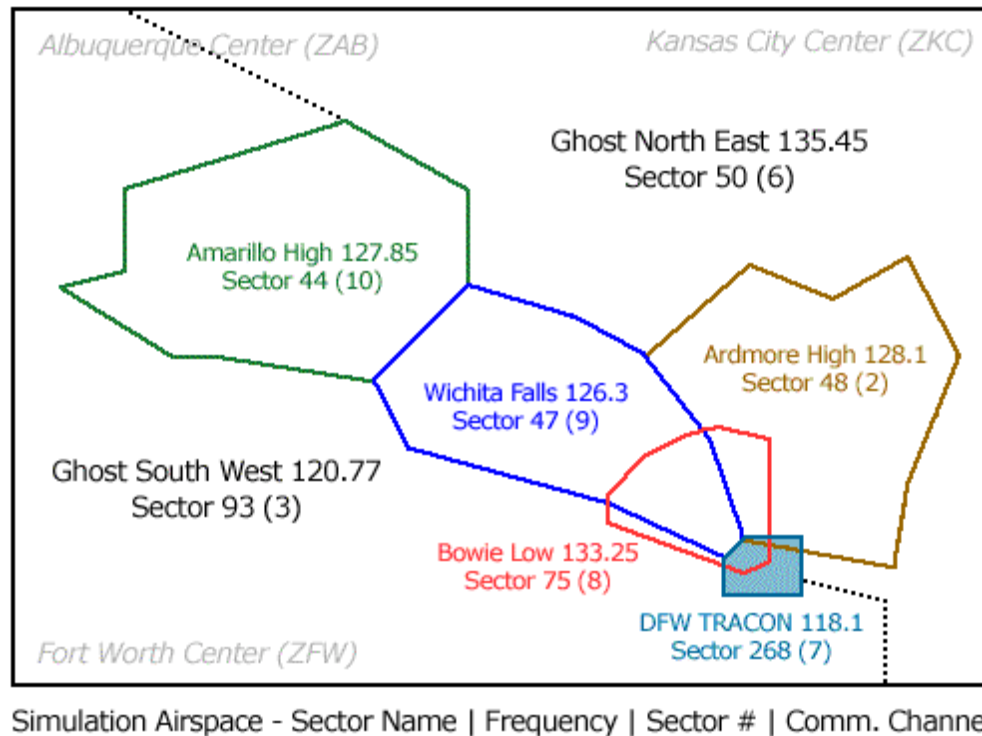
### ***Participants***

Five current, full-performance level controllers familiar with the study's specific airspace sectors participated on the ground side. Mean years as an active controller was 18.

On the air side, eight current commercial passenger aircraft pilots participated. Mean total flight hours was 11,600, with a group mean of 3,200 hours flying glass cockpit aircraft.

Support personnel included three cohort (retired) controllers who manned two peripheral Centers, and one TRACON sector. On the ground side, ten General Aviation (GA) or higher rated

pseudo-pilots flew general traffic aircraft using Multi-Aircraft Control System (MACS) stations (see description below).



**Figure 1. Simulation Environment Showing ARTCC Divisions and Sectors Used in the DFW Northwest Arrival 'Corridor'**

### ***Facilities and Equipment***

Three NASA Ames Research Center laboratory facilities were utilized. The Airspace Operations Lab (AOL) provided separate facilities for the participant and confederate controllers, and the ten pseudo-pilots. The Flight Deck Research Lab (FDRL) provided facilities for four participant pilots. The Crew Vehicle Systems Research Facility (CVSRF) high-fidelity simulator provided a station for two pilots. The two remaining pilot participants were connected to the simulation environment from remote locations.

Controller equipment included large screen displays, each equipped with the CTAS decision support tool [2]. The FDRL and remote station pilots were each equipped with the PC\_Plane

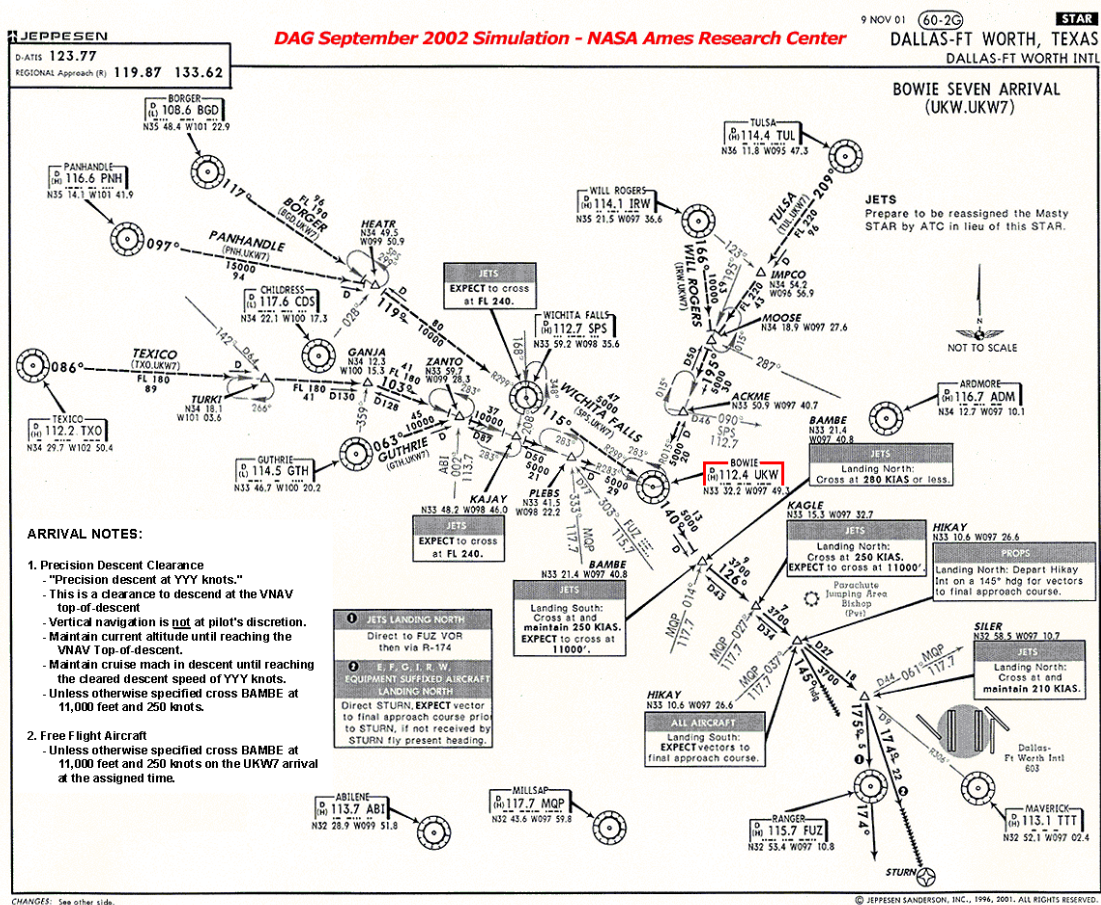
desktop simulator and a CSD, as shown in Figure 3 [3,9]. The CVSRF pilots 'flew' a high-fidelity simulator supplemented with a CSD.

Pseudo-pilots were equipped with MACS stations [10]. Each station has an aircraft list, permitting the operator to select a specific flight, and a suite of tools via which to action the aircraft.

### ***Simulation Airspace Environment***

The northwest arrivals 'corridor' into Dallas/Ft. Worth International Airport (DFW) was used for the simulation (see Figure 1).

The transition fix into the TRACON was BAMBE for DFW arrivals (GREGS for Dallas Love Field arrivals). The metering fix for DFW arrivals was BAMBE (see Figure 2).



**Figure 2. Bowie Seven Arrival Chart into DFW**

## Procedure and Test Conditions

**Training:** All participants and support personnel received a DAG-TM overview and study briefing on day one. On day two, controllers and participants separated and undertook individualized training in the use of their respective decision support tools, and the unique and common operating and communication procedures. On day three, a set of training scenarios was run to provide all participants and support personnel with practical experience.

**Design:** On day four, data collection runs began. Three scenarios were completed each day, counterbalanced over four days – for a total of 12

data collection runs. A briefing was held each morning and a de-brief was held each afternoon.

A single variable, mode of operation, was manipulated. The reader is referred to the NASA Ames Research Center DAG-TM Simulation, September 2002 – Final Report for a detailed description of the test scenarios, levels of applicable equipage, and rules-of-the-road applicable to each condition [11].

The **BASELINE** condition represented current-day operations with the exceptions that 1) Air Traffic Control (ATC) was equipped with the CTAS Traffic Management Advisor (TMA) tool that optimizes the scheduling of arrival aircraft, and 2) all aircraft were ADS-B equipped with proximal traffic visible on the

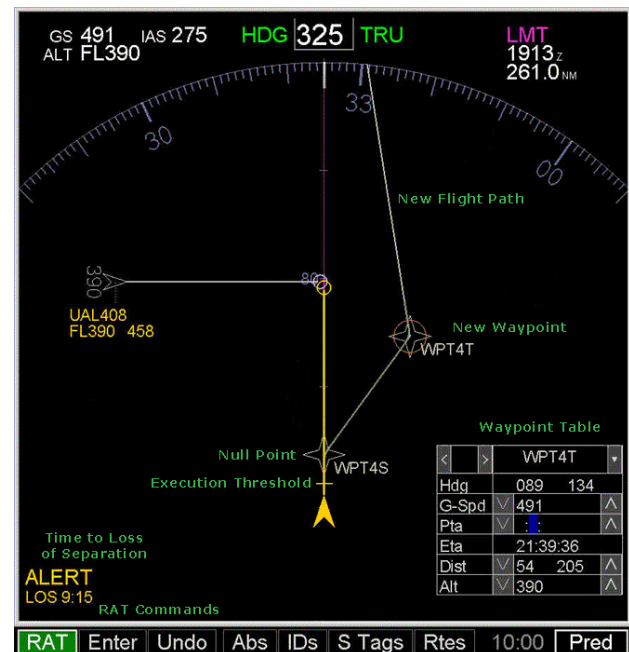
CSD. With the exception of departure and overflight traffic, each aircraft flew through en route airspace, transitioned into the TRACON, and landed, at all times being under positive ground control.

In the **CE 5** condition, participant aircraft were equipped with a CSD (see Figure 3) that facilitated autonomous operation – including conflict detection and alerting, route planning/re-planning and execution – independent of any ground-side approval. These free-flight aircraft were nonetheless required to meet their Required Time of Arrival (RTA) at the metering fix, and transition to positive ground control in the low altitude en route sector.

In the **CE 6** condition, all aircraft were again equipped with a fully functional CSD, but were under positive ground control at all times. Participant aircraft could, however, ‘negotiate’ a route change with ATC. Negotiation was done by data-linking a proposed route change to ATC, receiving in return a data-link approval or denial. Less than optimal routing was a primary motivation for participant flight crew to request a route change. The management of sequencing and spacing into the airport was a primary ground-side consideration in reviewing and accommodating route change requests.

In both the CE 5 and CE 6 conditions, **CE 11** in-trail spacing on approach using the CSD was executed by piloted participant aircraft, when directed by ATC (see [12] for a detailed CE 11 description). In short, ATC issued limited delegation clearances to terminal area arrival aircraft, comprising a lead aircraft to follow and a temporal spacing value. The trailing aircraft then used their CSD to identify and ‘mark’ the lead aircraft, set the spacing value in the CSD, and monitored the system as it manipulated auto-throttle control with the goal of achieving and maintaining the assigned spacing. Graphical and text elements

on the CSD closed the loop in terms of feeding back information to the pilots.

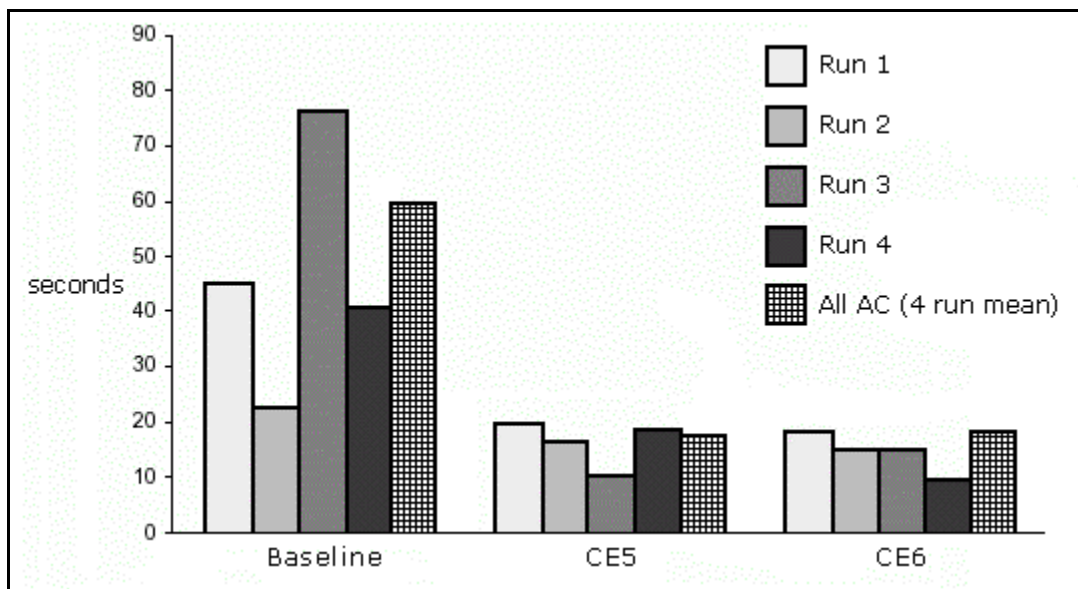


**Figure 3. Cockpit Situation Display**

## Data Collection

Dependent variables included system-level and human performance metrics. The simulation software, both in the AOL and FDRL, recorded and computed several system-level metrics to measure system capacity, complexity, efficiency, and safety. Measures included arrival delivery accuracy, arrival spacing and altitude deviations, and separation violations.

Subjective, or self-reported data, were gathered using a set of questionnaires. Participants completed a post-run questionnaire after every experimental run and a post-simulation questionnaire at the end of the study. Both questionnaires addressed usability, suitability, and acceptability issues with the advanced technologies and the acceptability of each concept element.



**Figure 4. Absolute Meter Fix Crossing Deviation: Participant Aircraft (Versus the All-Aircraft Average Across All 4 Runs)**

Subjective workload assessments were collected from controllers using the Air Traffic Workload Input Technique (ATWIT). Controllers were required to rate their workload via a keyboard on a scale of 1 to 7, at 4-minute intervals throughout each simulation run. In addition, controller and pilot workload responses were collected via a modified NASA Task Load Index (TLX) administered at the end of each run.

## Results

### *Air-Side Results*

**Metering Fix Compliance:** In baseline runs, participant aircraft were under positive ATC control, and responsible for implementing directions from ATC, similar to current day operations. In CE 5 runs, participant aircraft were free to maneuver in maintaining separation assurance and meeting their Scheduled Time of Arrival (STA) at the BAMBE metering fix. In CE 6 runs, participant aircraft were free to negotiate preferred routings, but were still expected to meet their STA. In all cases, controllers and pilots were informed that crossing BAMBE within +/- 15 seconds of the STA was considered “on time.”

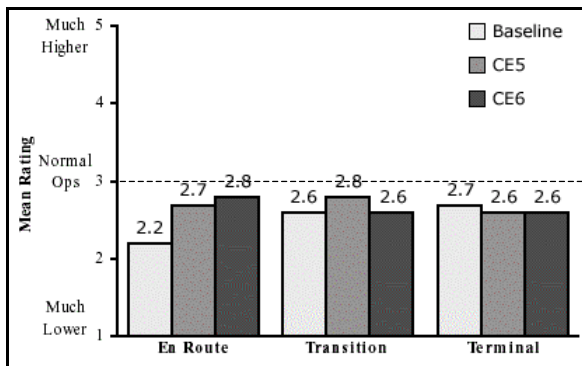
While the performance of participant aircraft is not independent of the simulation traffic managed by pseudo-pilots, Figure 4 illustrates the absolute meter fix crossing time deviations for only the experimental aircraft, by condition and run. Mean STA error for participant aircraft in the baseline condition was 46.2 seconds (59.9 seconds for all aircraft); in CE 5, 16.3 seconds (17.1 seconds for all aircraft); and in CE 6, 14.5 seconds (17.5 seconds for all aircraft).

**Approach Spacing:** In the absence of a comparative baseline condition, spacing during approach was assessed descriptively from the air-side, with the goal of defining some initial parameters against which to assess later simulation study results. The data was collapsed across the CE 5 and CE 6 runs, the result being 26 instances (or 40% of the total possible trials) where participant aircraft engaged in the spacing routine at the request and direction of ATC.

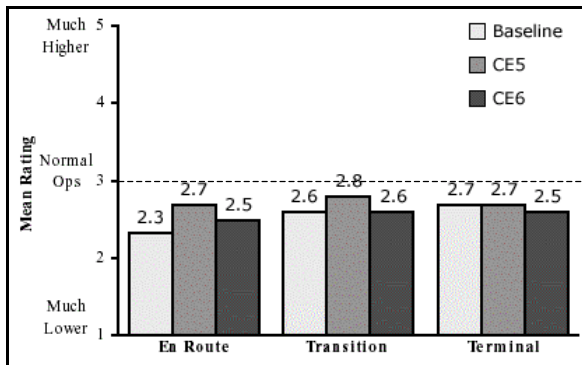
Mean total time with spacing engaged was 4 minutes, 35 seconds, the average temporal in-trail value issued by ATC was 98 seconds, and the average slant range between the two aircraft decreased 1.5 nautical miles over the course of the routine. Rate of closure for the trailing aircraft averaged 0.34 nautical miles per minute. There

were no separation violations involving any participant aircraft undertaking approach spacing, however, this otherwise positive result may have been more of a consequence of conservatism on the part of the TRACON controller (see the air-side discussion section below).

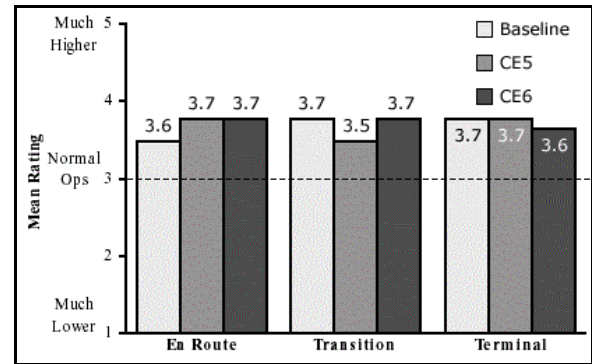
**Human Performance Ratings:** As compared to current day operations (with current day equipment), flight crew ratings were positive. Participant pilots generally rated mental workload and temporal demand as being less overall than that likely to be experienced under current day operations, with situation awareness being better (see Figures 5-7 below). In each case, a rating of 3 was the equivalent of current day operations, a rating of 1 was less than current day operations, and a rating of 5 was higher than current day operations.



**Figure 5. Pilot Ratings of Mental Workload By Condition**



**Figure 6. Pilot Ratings of Temporal Demand By Condition**



**Figure 7. Pilot Ratings of Situation Awareness By Condition**

**CSD Usability Ratings:** Pilot participants rated CSD usability and function-to-task usefulness with respect to 1) aircraft information, 2) route information, 3) the alerting system, 4) the route analysis tool, 5) the approach spacing tool, and 6) user settings – a total of 28 individual features. Only the initiation of approach spacing using the CSD tool bar was found to be less than optimal (see the air-side discussion section below).

### Ground-Side Results

The main focus of the analyses was an initial feasibility assessment of the three concept elements CE 5, CE 6, and CE 11, and to determine whether the envisioned benefits associated with these concepts could be validated in human-in-the-loop simulations. Detailed results were reported in [13] and [14]. A summary is presented below.

### Simulation Setup

The benefits of the CE 11 concept could not be quantified because the TRACON controller changed his strategies during the data collection runs. The distance-based radar separation requirement and time-based in-trail spacing seemed to create a mismatch in the controller's strategies in the airspace management. Time-based spacing required aircraft to follow a specified number of seconds behind a lead aircraft. This strategy seemed to run counter to the current day strategy of keeping the distance spacing relatively constant and then slowing the aircraft just before the final approach.

Trajectory-based arrival metering for CE 5 and CE 6 was enabled by providing controllers with a timeline display depicting estimated times of arrival (ETAs), scheduled times of arrival (STAs), and the

current delays at the meter fix. In order to deliver aircraft at their STA, a set of CTAS-based decision support tools (DSTs) were integrated with the radar displays to assess and adjust aircraft trajectories using advised speeds and/or route modifications. The STAs were communicated to pilots of free maneuvering aircraft as required times of arrival (RTAs). An experimental on-board RTA function was designed to meet the assigned time within a 15 second interval. Autonomous and managed aircraft were merged at the metering fix using the schedule for coordination.

The baseline was simulated as a control condition approximating current day metering operations with only managed aircraft.

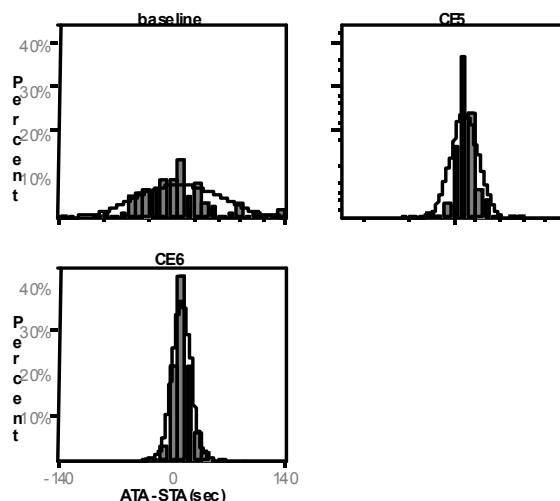
In the simulation runs, the CTAS TMA was configured to schedule aircraft at the meter fix with a minimum spacing of seven nautical miles in trail, which resulted in an 82-second minimum time interval between subsequent aircraft. Controllers in the baseline condition were asked to deliver aircraft at seven miles in trail to the TRACON, using meter lists and a delay indication at the aircraft symbol. In the experimental conditions, controllers and pilots were asked to deliver each aircraft within 15 seconds of its meter fix STA using the tools described above.

#### STA Compliance at the Meter Fix

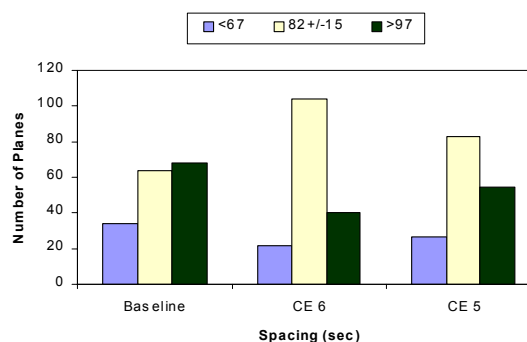
To determine arrival delivery accuracy, the difference between the actual time of arrival (ATA) and the STA was examined. Although the means of the difference were similar across conditions (8.1, 11.4, and 12.3 seconds delay for baseline, CE 6, and CE 5, respectively), there was significantly more variability under the baseline condition (SD = 53.9) than either CE 6 (SD = 11.4) or CE 5 (SD = 17.2) (see Figure 8).

#### Inter-Arrival Spacing at the Meter Fix

Figure 9 shows the inter-arrival spacing at the meter fix. The number of aircraft that were spaced within 15 seconds of the desired 82-second spacing was higher in CE 6 (104) than in baseline (64), with CE 5 in the middle (83). The number of aircraft below the desired spacing interval (i.e., less than 82–15 seconds or 67 seconds) was 34, 21, and 26 for baseline, CE 6, and CE 5, respectively.



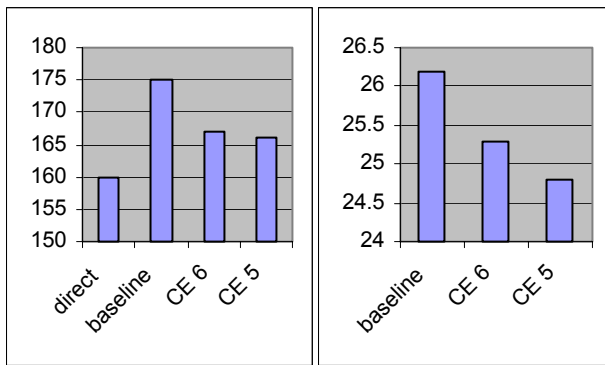
**Figure 8. Arrival Accuracy (ATA – STA)**



**Figure 9. Spacing Between Aircraft at the Meter Fix**

#### Flight Path Efficiency

To evaluate efficiency, the flight path length and flight time from the point at which the STA was assigned to the meter fix was examined. Figures 10 and 11 show the results of the average path length and flight time for the different conditions.



**Figures 10 and 11. Path Length (nm) and Flight Time (min) from STA/RTA Assignment Point to Meter Fix**

### Workload

Controller workload was measured during the simulation using the ATWIT and afterwards using post-run questionnaire ratings for mental demand, effort, frustration, and performance. Workload levels between CE 5 and CE 6 were equivalent. The main workload impact of DAG-TM operations compared to the baseline was observed at the low altitude sector (Bowie), where the controller reported less mental demand, effort, and frustration and achieved a higher level of performance.

The self-spacing concept CE 11 showed lower workload ratings in comparison to the baseline in ATWIT ratings. Post-run ratings showed slightly lower effort but higher frustration in CE 11.

### Tool Usability

In the post-simulation questionnaire, controllers rated the usability and usefulness of several controller workstation features. Most features were evaluated as quite useful, with the conflict list as the only exception ( $M = 2.8$ ; 1 = unnecessary, 5 = vital). The highest rated features were timeline, speed advisories, speed information in the data block, and route modification tool. All features were rated positively for usability except the conflict list and the route modification tool, which received neutral ratings ( $M = 3.0$ ).

Controllers also indicated that the amount of clutter caused by the information presented on the display was somewhat unacceptable,  $M = 2.8$  (1 = unacceptable clutter, 5 = not a problem). They were able to distinguish autonomous from managed aircraft ( $M = 4.8$ ), and the interface for interacting

with a mix of managed and autonomous aircraft was rated adequate ( $M = 4.3$ ).

### Concept Acceptability

Controllers' average rating for overall acceptability of CE 6 operations compared to current day operations was 3.8 (1 = much less acceptable, 5 = much more acceptable). More specifically, controllers were asked to rate the acceptability of two elements of the concept in our simulation: pilots modifying speeds without ATC coordination and pilots sending clearance requests (1 = completely unacceptable, 5 = completely acceptable). Results were 4.0 and 4.8 respectively.

For acceptability of the free maneuvering concept (CE 5), the controllers' average rating was 2.5 (1 = much less acceptable, 5 = much more acceptable). Controllers were also asked to rate the acceptability of specific aspects of the free maneuvering concept: procedures and phraseology for applying the rules-of-the-road, criteria for canceling autonomous control, and procedures and phraseology for canceling autonomous control (1 = completely unacceptable, 5 = completely acceptable). Their ratings were 3.5, 3.8, and 4.0 respectively.

The TRACON controller generally liked the self-spacing concept. He had no problems operating the user interface that provided in-trail spacing and advisory information in an expanding data block. However, he found terminal spacing in CE 11 to be less acceptable than normal current-day operations, with the biggest concern being when to initiate in-trail spacing. His rating was 2.0 (1 = unacceptable, 5 = acceptable).

## Discussion

### Air-Side Discussion

In the CE 5 and CE 6 conditions, participant aircraft were free to maneuver and free to negotiate modified routes respectively, but concurrently still expected to make every effort to meet their ground-issued BAMBE meter fix STA. The implementation of route changes independent of the ground, and with ground-side approval had little effect on participant aircraft meeting their STA, as compared to the total aircraft population. The effectiveness of the CSD's route modification and STA compliance

tools will be further assessed as the number of independently operated participant aircraft grows in number in future simulations.

Execution of CE 11 in-trail approach spacing appeared to be successful in terms of pilot acceptance for the concept and its air-side implementation during the simulation. That no separation violations were recorded is positive. However, the TRACON controller was conservative in setting the temporal spacing value, frequently opting to use a value in excess of the recommended 90 seconds. In an effort to 'push' the CE 11 concept and test it more rigorously, the temporal spacing value will be set by procedure in future studies.

Pilot participants rated initiation of approach spacing parameters via the CSD tool bar as less than optimal in terms of usability. Among their recommendations included reducing the number of procedure setup steps, and a simpler method for modifying an existing temporal spacing value (as compared to having to completely re-initiate the procedure). These and other recommendations concerning better communication of the precise temporal and physical distance between the lead and trailing aircraft have since been implemented.

### ***Ground-Side Discussion***

The simulation described in this paper demonstrated that the DAG-TM concept elements for free maneuvering and trajectory negotiation have a good potential to provide the envisioned benefits and are operationally viable. Aircraft were delivered more accurately on schedule and the inter-arrival spacing between aircraft was more consistent than in current day operations. These results are likely due to the 4D trajectory-based metering that provides controllers and pilots with the tools to deliver aircraft within seconds rather than minutes of their scheduled time. Additionally, the trajectory planning to meet the scheduled times at the metering fix takes place mostly in the high altitude sectors and takes workload of the low altitude sector controllers without increasing the high altitude sector controllers workload. More efficient flight paths in terms of time, distance, and altitude could also be achieved [15].

The results were mostly consistent between CE 5 and CE 6, indicating a slight efficiency gain for CE 5, suggesting that autonomous aircraft can potentially chose a more efficient flight path.

The controllers assessed all tested concept elements acceptable, with a preference for the trajectory negotiation concept (CE 6). The experiment indicates that mixed operations (CE 5) are possible in high-density airspace, but procedures, roles, and responsibilities need some refinements. The meter fix schedule appears to be an appropriate means for coordinating autonomous and managed aircraft entry into controlled airspace. The number of autonomous aircraft needs to be increased in future experiments to assess the impact of these operations on the ground system further. The self-spacing concept (CE 11) was not exercised sufficiently to draw any conclusions about benefits and feasibility. Initial controller feedback indicates that it might be acceptable but needs a more thorough investigation.

### ***Air-Ground Integrated Perspective***

Success of the DAG-TM concept requires, in large part, advances in air-ground coordination. The integration of air-side and ground-side roles, responsibilities, and procedures has been an important focus in developing a distributed concept [15]. Therefore, issues pertaining to rules-of-the-road, conflict resolution, cancellation of autonomous control, and assigned time of arrival are paramount in determining concept feasibility.

**Rules-of-the-road:** Rules-of-the-road were developed to specify conflict resolution responsibility. The rules were based on an aircraft's status (arrival, departure, or overflight), level of control (managed or autonomous), and flight path (climbing, descending, or overtaking) [11]. In most situations, the rules provided an adequate means for determining resolution responsibility. However, there were specific conflict situations that presented problems. At times, pilots had difficulty determining if an overtake was occurring (i.e., a conflict with an angle of approach less than 20 degrees) and who had the right-of-way in certain overtake situations.

Researchers concluded that information indicating resolution responsibility should be

provided automatically to controllers and flight crews. Providing this information would likely reduce the ambiguity that existed in the current implementation and may therefore result in more timely and efficient maneuvers. In addition, this information would preclude pilots and controllers from having to make the determination, thereby reducing mental workload.

**Conflict resolution:** The rules-of-the-road established which aircraft was responsible for resolving a conflict without imposing a specific resolution strategy. This method offered controllers and pilots the flexibility to adopt the strategy they preferred. However, it may have also caused problems in situations where the aircraft not responsible for resolving the conflict initiated a change, while the other aircraft was implementing its own resolution strategy. Unanticipated movements may have increased the complexity of the situation, or even raised the likelihood of a separation violation. For example, one controller described a situation where, by the time an autonomous aircraft responsible for resolving a conflict moved, the controller had already sent a resolution clearance to the managed aircraft.

A possible solution is to investigate the feasibility of automated resolution advisories. Although there is literature available on the functionality of different conflict detection and resolution algorithms, there is little known about the implications of these algorithms on integrated controller and flight crew strategies, performance, and interaction. Considerable research effort is needed to evaluate issues related to the coordination of automated resolutions (e.g., differences in controller-pilot resolution strategies).

**Cancellation of autonomous control:** The cancellation of autonomous control was a relatively infrequent event, occurring only twice in 28 flights. However, when it occurred, the question arose as to whether autonomous control should be reinstated or whether the aircraft should remain under the controller's control. The following example illustrates the need for rules to coordinate the exchange of control between flight deck and controller.

The one time autonomous control was reinstated occurred during the initial descent phase. The pilot of an autonomous aircraft requested that

the controller take control because of a pending traffic conflict. The controller assumed control and resolved the conflict. Afterwards, the pilot requested, and was granted, autonomous control. However, the aircraft's proximity to the meter fix negated the benefits of free maneuvering. In the end, the actions only increased pilot and controller workload.

**Assigned time of arrival:** All arriving aircraft were constrained by an assigned arrival time that was conveyed to the pilots as STA and RTA clearances. Aircraft, whether free maneuvering or negotiating trajectory changes with ATC, were instructed to meet these arrival times.

The assigned arrival time was a powerful concept that was important in linking air and ground. TMA-generated RTA/STAs provided controllers and pilots with a common perspective on the traffic flow and likely facilitated air-ground coordination and system efficiency. The significance of this concept was well demonstrated by the desire of pilots to maintain their scheduled arrival time, as well as consider the RTAs of other aircraft when resolving traffic conflicts.

## Conclusions

The initial results demonstrated feasibility and benefits of CE 5, CE 6, and CE 11. The participant feedback also indicated that these concepts would be acceptable. The study also identified DST, computer-human interface (CHI), and procedural considerations where improvements are needed.

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